Coho and Climate: Forecasting Marine Survival of Puget Sound Coho Salmon Using Climate Indices

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Introduction

Each year the State of Washington makes a forecast of the number of adult coho salmon (*Oncorhynchus kisutch*) that will return to Washington waters. The forecast is conducted jointly by the Washington Department of Fish and Wildlife (WDFW) and the Northwest Indian Fisheries Commission (NWIFC) in January and February of each year to allocate fishing effort to commercial fishers, native tribes, and sport fishers.

Estimates are made of adult returns for the summer months (July–September) to Puget Sound. Estimates of the total number of hatchery smolts (juvenile salmon) entering the marine environment are multiplied by a five-year average of marine survival (% of smolts that return as adults; hereafter MS) of coho to estimate the number of returning adults. In the early 1990s, this method has over-forecasted MS, revealing a weakness in the forecasting technique, the application of the five-year average of MS. The way in which interannual climate-variability influences MS of Puget Sound coho salmon needs to be understood to improve the forecast.

Evidence from the Oregon coast suggests that the majority of marine mortality occurs in the first three months of ocean residency (W. G. Pearcy, pers. comm. Feb. 1997). Beamish, et al. (1995) found synchronous timing of an increase in mean temperature of the Strait of Georgia and MS of hatchery-reared chinook salmon released into the Strait of Georgia. Francis and Hare (1994) found a relation between a climate indices and subsequent returns of salmon in Alaska, adjusted for year of entry. Holtby, et al. (1990) found that growth during the first few months of life in the ocean was well correlated with total marine survival. This evidence suggests that the effects of climate variability on salmon are manifested in the first year of ocean residency.

Spatial and temporal variations exist at the regional scale in coho salmon MS, a measure of salmon productivity. Coronado-Hernandez (1995) demonstrated clearly that coho salmon originating in inland waterways (Puget Sound and Strait of Georgia; hereafter PS and GS, respectively) have higher MS (long-term average ≈ 8.5%) than coastal coho (Washington coast and west coast of Vancouver Island, hereafter WC and WCVI, respectively) (long-term average MS ≈ 3.9%). PS coho MS peaked at 17% in 1984, and SG coho MS peaked at 26% in 1973. Coronado-Hernandez (1995) calculated MS from coded wire tag (CWT) data dating to 1971. The inland waterways of the PNW must act like a buffer from the harsher conditions of the coast.

Why do coho salmon from Puget Sound have a different pattern of survival than coho salmon from the Strait of Georgia, and how does climate variability regulate these patterns? I postulate that the differences in patterns of coho MS result from differences in localized oceanographic conditions at the time and place that juvenile salmon enter the marine environment. The localized oceanographic conditions (strength of upwelling [coastal areas], freshwater input [inland waterways], temperature, primary production, etc.) are an integration of climate variability.

Objectives

The objectives of my research are to:

- Develop an index of marine survival;
- Characterize the climate of Puget Sound in:
  - poor marine survival years, and
  - good marine survival years; and
- Develop a forecast model of marine survival based on the climate of Puget Sound.

Puget Sound and Climate Variability

Puget Sound is chosen as the first step of the investigation because it stands out as an anomaly, both regionally (salmon have higher survival than the coast), and sub-regionally (salmon have different patterns of survival than nearby areas, such as the Strait of Georgia). To illustrate how coho salmon are affected by climate variability, it is helpful to develop a conceptual model. Puget Sound, a fjord estuary, has an input of fresh water and an input of salt water. Changes in these inputs can have dramatic effects on both circulation and mixing patterns.

Ebbesmeyer et al. (1988) described decade-scale changes in deep-water input into Puget Sound. The paper linked decadal changes in the atmosphere to changes in the physics of the marine waters of Puget Sound. When the Aleutian Low pressure center is positinioned over the eastern Pacific Ocean, storms drop less precipitation over Washington. This causes a decrease in freshwater input into Puget Sound, which in turn causes a rearrangement of the density profile of the Strait of Juan de Fuca and decreases the difference in density across the entrance (Admiralty Inlet) of the Puget Sound basin (Ebbesmeyer et al., 1988). This difference in density causes the influxing oceanic water to enter along the bottom. In the opposite regime, when the Aleutian Low is centered over the western Pacific, the influx of oceanic water occurs at mid-depth.

Changes in the timing and magnitude of inputs (fresh water, salt water) to Puget Sound cause changes in the conditions necessary for plankton production (both phytoplankton and zooplankton). Optimal conditions for phytoplankton blooms arise when a balance occurs between mixing, light, and stratification (Strickland 1983, p. 45). Mixing is important for bringing nutrients to the surface, stratification is important for keeping phytoplankton near energy from the sun, and light is necessary to stimulate photosynthetic processes in phytoplankton.

Forecast Model

The forecast input variables need to be easily accessible to WDFW and NWIFC to eliminate costly sampling protocols. It is important to note that a forecast is only being made on MS of coho salmon, not a forecast of oceanographic variables. The forecast will be based on oceanographic conditions that have occurred and have been measured.

Preliminary results suggest that stream flow (freshwater input) into Puget Sound is higher in the spring of good coho-MS years, and shows a lower peak in the spring in poor coho-MS years. Sea surface temperature is cooler in good MS years, and warmer in poor MS years. Upwelling is generally higher during the summer of ocean entry in good MS years, and lower during the summer in poor MS years. These results, although preliminary, suggest that conditions for good marine survival are correlated with cool, wet years in the Puget Sound region. Initial model formulations have shown a significant improvement to the current forecast model by using a climate index incorporating stream flow and sea surface temperature.

Discussion

Puget Sound coho marine survival appears to be driven by changes in the oceanographic and climatic conditions in the Puget Sound region. Good-survival years are associated with high spring stream flow, high April-15th snow pack, cool sea surface temperatures, cool air temperatures, and strong summer upwelling. It is hypothesized that changes in the mixing and circulation regimes of Puget Sound have altered the timing and magnitude of primary production peaks, and that coho salmon are "missing" this peak in primary (and ultimately secondary) production. It is possible that changes in salinity drive coho out of Puget Sound, thereby causing them to miss the spring plankton bloom, but few data are available to support this hypothesis. I propose that coho are missing the peak of the spring bloom because timing of coho ocean entry is constant, while the timing of the spring bloom is occurring earlier.

As more is learned of the intricate web of life that spans the thin biosphere of Earth, the more evident it becomes that no single branch of science can begin to answer even the simplest of ecological questions. Fishery science is not immune from this affliction and is a science ripe for interdisciplinary research. Investigating the link between the living and physical components of large ecosystems is necessary if decision-makers are to ensure a long-term yield from a finite resource. Understanding the range of variation both in the physical environment and the parallel variability of biological systems is tantamount to proper "management."

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